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A Novel Technique for Modification of Images for Deuteranopic Viewers

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Abstract: About 8% of men and 0.5% women in world are affected by the Colour Vision Deficiency. As per the statistics, there are nearly 200 million colour blind people in the world. Color vision deficient people are liable to missing some information that is taken by color. People with complete color blindness can only view things in white, gray and black. Insufficiency of color acuity creates many problems for the color blind people, from daily actions to education. Color vision deficiency, is a condition in which the affected individual cannot differentiate between colors as well as individuals without CVD. Colour vision deficiency, predominantly caused by hereditary reasons, while, in some rare cases, is believed to be acquired by neurological injuries. A colour vision deficient will miss out certain critical information present in the image or video. But with the aid of Image processing, many methods have been developed that can modify the image and thus making it suitable for viewing by the person suffering from CVD. Color adaptation tools modify the colors used in an image to improve the discrimination of colors for individuals with CVD. This paper enlightens some previous research studies in this field and follows the advancement that has occurred over the time. It also approaches different methods of modifying and adjusting images so that the persons suffering from dichromacy are able to better perceive image detail and color dynamics. This paper includes three algorithms; they are LMS daltonization, color contrast enhancement, and LAB color adjustment. Two separate technique are also used for evaluation of the effectiveness of these techniques. First; the simulation of deuteranopia is done on both the original and processed images to observe the algorithm's effects from the perspective of a color blind viewer. Second; delta E image is obtained between the two images in order to assess the extent to which the image changes from the perspective of a non-color blind viewer and also, the Elapsed time is calculated for the algorithms. A brief comparison is also done between Color contrast enhancement, LAB color adjustment and LMS daltonization.

Keywords: Deuteranopia, Dichromacy, CVD, LMS Daltonization, RGB Color Constrasting, LAB Color Correction, Elapsed time.

I. INTRODUCTION

Human normal color vision requires three kinds of retinal photoreceptors. These are called L, M, and S cone cells, and have higher sensitivity to the long, medium, and short wavelengths of the visible spectrum, respectively. The specific type of photopigment contained in each kind of cone cell determines its spectral response. Some natural variations in the composition of these photopigments can shift their spectral sensitivities to different bands of the visible spectrum [1].

In this case, the affected individuals are called anomalous trichromats, and can be further classified as protanomalous, deuteranomalous, or tritanomalous, if the affected photopigment is associated with the L, M, or S cones, respectively. The bigger the shift, the more the individual's color perception will vary with respect to the perception of an individual with normal color vision (normal trichromat). The person can be classified as protanope, deuteranope, or tritanope, according to the type of the missing photopigment (L,M, or S, respectively). Much rarer conditions include the cases of individuals with a single kind of photopigment (cone monochromats) or no functional cone cells at all (rod monochromats).

The following figure helps to understand how the color image appears to a color blind viewer depending on the type of color blindness.

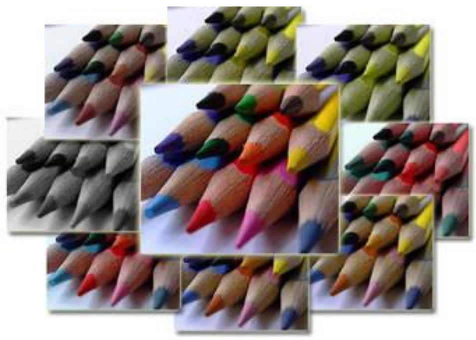

Fig1.Image perception of a Color-blind person

As a consequence of the existence of three types of photoreceptors, normal color vision spans a 3-D color space. The color gamut of a dichromat, on the other hand, is only two-dimensional and can be represented by a surface patch in the same 3-D color space. Such a reduced gamut is the cause of the ambiguity experienced by

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dichromats: many different colors are perceived as the same, when projected onto such patches. For anomalous trichromats, the color gamut falls in between these two extremes, moving towards the gamut of a dichromat as the degree of severity of the anomaly increases. For spectral shifts of approximately 20 nm, the perception of an anomalous trichromat becomes similar to the perception of a dichromat [1, 2].

As stated by William Woods [3], Color blindness affects roughly ten percent of human males. It is possible for a woman to be color blind, but the because a defect in the X chromosome leads to main type of color blindness, so most color blind individuals are men. About ninety-nine percent of them suffer from some sort of red-green deficiency, where a person is unable to differentiate properly between red and green. A non color blind person can perceive three wavelength groups. Dichromacy is a general term for a person's lack of ability to perceive one of these three wavelengths. There are three types of receptor cones in the normal human eye that are often referred to as red, green, and blue (RGB); technically they are receptors of long, medium, and short (LMS) wavelengths respectively. Three types of complete dichromacy exist. Protanopia is an absence of red cones, deuteranopia is an absence of green cones, and tritanopia is an absence of blue cones.

Types of color blindness:

A. Monochromacy -If there is no cone or only one type of cone present at retina of eye then it is called Monochromacy. In Monochromacy, person is unable to see any color. All things seem to be black, white and gray.

B. Dichromacy- If there are only two types of cones present at retina of eye then it is called Dichromacy. In Dichromacy, any one type of cones is missing. So information about that particular wavelength is lost. Dichromacy is again of three types according to the missing cone:-

1) Protanopia: If the type of missing cones is L-cone then it is called Protanopia. Due to protanopia, long wavelength color information is lost, so the person suffering from protanopia is unable to see red color. This is called 'Red blindness'.
2) Deuteranopia: If the type of missing cones is M-cone then it is called Deuteranopia. Due to deuteranopia, medium wavelength color information is lost, so the person suffering from deuteranopia is unable to see green color. This is called 'Green blindness'.
3) Tritanopia: If the type of missing cones is S-cone then it is called Tritanopia .Due to tritanopia, short wavelength color information is lost, so the person suffering from tritanopia is unable to see blue color. This is called 'Blue blindness'.

C. Anomalous Trichromacy-In this condition all the types of cones are present but they are not aligned properly. Hence, the sensitivity to a particular colour is reduced. Depending upon which cone is not aligned properly it is further divided into:

1) Protanomaly: In Protanomaly the sensitivity to red colour is reduced.
2) Dueteranomaly: In Dueteranomaly, the sensitivity to green colour is reduced.
3) Tritanomaly: In Tritanomaly, the sensitivity to blue colour is reduced.

TABLE I MAJOR GENETIC COLOR DEFICIENCIES[4]

Name	Cause	Prevelance
Dichromacies		
Protanopia	Missing L cone	males:1.0% females: 0.02%
Deuteranopia	Missing M cone	males:1.1% females: 0.1%
Tritanopia	Missing S cone	Very rare
Anomalous Trichromacies		
Protanomaly	Abnormal L cone	males:1.0% females: 0.02%
Deuteranomaly	Abnormal M cone	males:4.9% females: 0.04%

II. LITERATURE REVIEW

Inspite of the relevance of understanding how individuals with CVD perceive colors, there has been little work done in simulating their perception for normal dichromats. Over years, there have been many techniques but none of the previous approaches is capable of handling dichromacy in the way that this paper does.

Based on the report on unilateral dichromat individual by [5], achromatic colors as well as some other hues are perceived similarly by both eyes (approximately wavelengths of 475 nm and 575 nm by individuals with protanopia and deuteranopia, and 485 nm and 660 nm by tritanopes). This formed a basis for development of many techniques for image adjustment and modification as it provided effective insight to the perception of images as observed by person with CVD.

In the work done by [6], this gamut has been mapped in the XYZ color space. They also mapped confusion lines in this color space, which represent directions along which there is no color variation according to dichromats perception. By projecting colors through confusion lines into the reduced gamut, they have defined an accurate technique for simulating dichromacy.

Latter, some other similar works have been developed by[7]. Amongst others, the technique proposed by [7] is the most referenced of all existing simulation techniques. In this technique, the color gamut of dichromats is mapped to two semi-planes in the LMS color space, while the authors constrained the direction of confusion lines to be parallel to the direction of the color space axes L, M, or S,

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depending on whether the dichromacy type is protanopia, deuteranopia, or tritanopia, respectively.

Figure (2) illustrates the process of projecting colors onto the semi-planes. For example, in case of simulation of deuteranopia (Figure 2(b)center) the colors are projected onto the semi-planes through the direction of the M axis. This process is analogous for protanopia (Figure 2(a) left) and tritanopia (Figure 2(c) right).

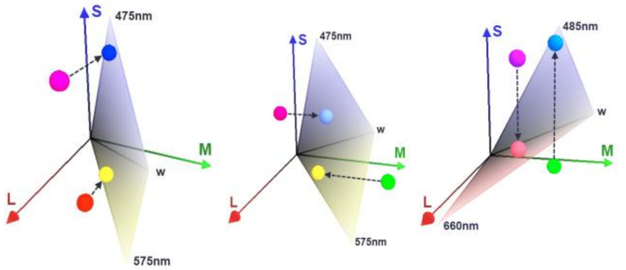

Fig 2. Illustrations of the technique for simulating (a) protanopia (left), (b) deuteranopia (center), and (c) tritanopia (right).

As shown in the above figure, the three graphs illustrate the technique for simulating the perception of individuals with dichromacy proposed by [7]. In the LMS color space, the original colors are orthographically projected to corresponding semi-planes, along the direction defined by the axis representing the affected cone. These techniques have produced very good results for the cases of dichromacy, but they can never be generalized to the other cases of CVD [8][9]. It has been found that both the techniques ie simulation and modification were successfully integrated into a visualization system, which allowed the practical validation of its results. Both works have been published in visualization journal [10].

In a paper presented by [11], a re-coloring algorithm to improve the accessibility for the color deficient viewers is proposed. This paper focused on protanopia, a type of dichromacy where the patient does not naturally develop “Red”, or Long wavelength, cones in his or her eyes, is considered. The algorithm proposed in this paper provided satisfactory output image distinguishable by color deficient viewers when applied to the original image and after some processing. A method in [12] proposed is that used thresholding to create a red color mask which was applied to the original image. After further processing it provided a satisfactory output image that was distinguishable by color deficient person. It was mainly to eliminate confusion between red and Green colors and was devised for Deuteranopia but it can also be extended for protanopia and tritanopia. A model is proposed in [13] which highlights mandatory features that software developers should consider while developing color blind applications. This model facilitates developers to address challenges faced by color blind by incorporating proposed features. A major work in the field of improving visualization for CVD viewers has been done by [4]. He proposed a new method for adapting digital images so that they are suitable for color blind viewers is presented.

In contrast to earlier automatic methods which formulate the problem of adapting images for color blind observers as one of optimization, it is demonstrated how it is possible to allow a user to compute a very wide range of adaptations in reasonable time under the control of a single variable

III. PROPOSED WORK

The prominent works regarding CVD are classified as methods for simulation and modification. The first group is Simulation; it provides the desired tools so that individuals with normal color vision can understand how some color stimuli are perceived by individuals with CVD. Such tools help to get a better view about the difficulties faced by these individuals. Moreover, it becomes easy to provide insights and feedback, like, on how to improve visualization experiences for individuals with CVD. Modification and adjustment algorithms, on the other hand, aim to change image colors and effects so that individuals with CVD can recover the lost color contrast to an extent. Besides, an efficient technique could be integrated to portable devices, which would impact these individuals’ daily lives.
The following block diagram shows the several steps on which the proposed paper depends:

Fig 3.Block diagram of image modification process

i. **Input image**-The image to be adjusted and modified is taken into consideration.
ii. **Pre-processing** –The Pre-processing of the image involves all the image acquisition to be performed and conversion into required planes to be done.
iii. **Feature Extraction**-Feature Extraction is the spine of whole process where the image is to be simulated so as to understand how the image is perceived by CVD viewer. Moreover, here one of the three algorithms is to be applied and implemented. As mentioned earlier, these algorithms are: LMS Daltonization, RGB Color Constrasting, LAB Color Correction.
iv. **Post processing**-Post-processing is the next step of this journey, where the reconstruction of image is performed so as to visualize the effects of the algorithms.
v. **Output image**-Finally, the output image is received which is used to calculate the Delta E value between two images. This helps in comparing the three algorithms in question and understanding their effects as being perceived by colorblind viewer and a non-colorblind viewer.

IV. METHODOLOGY & IMPLEMENTATION

If we want to understand the exact steps of image modification, then we can draw a detailed diagram that represents the sequential procedure:

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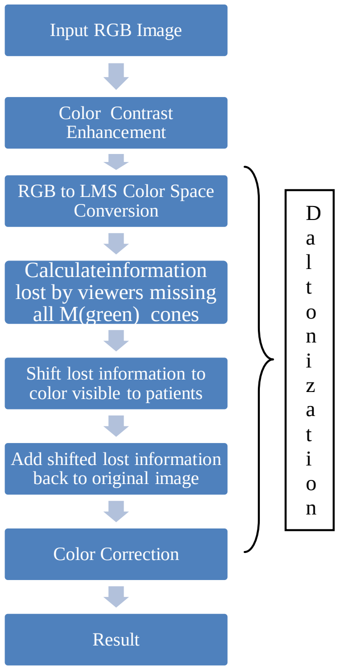

Fig 4: The Process Flowchart

A. Algorithms for Image Modification

1) Simulating Deuteranopia

To understand how an image is perceived by a deuteranopic person, it is required to simulate the image. This can prove the effectiveness of the algorithms we are proposing. A fairly simple and basic conversion method can be considered where the image is first converted into the LMS color space. As we are using Matlab as our platform, we must know that Matlab's imread function reads in images in the RGB color space, so it is must to convert from RGB to LMS.

This is a simple linear matrix multiplication operation as illustrated below:

$$\begin{pmatrix} L \\ M \\ S \end{pmatrix} = \begin{pmatrix} 17.8824 & 43.5161 & 4.11935 \\ 3.4565 & 27.1554 & 3.86714 \\ 0.02996 & 0.18431 & 1.46709 \end{pmatrix} * \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

This operation is applied to every pixel of the image and it yields a new set of pixels whose information is now defined for the LMS color space. As the image exists in the LMS color space, we can remove information associated with the M cone and replace it with information perceived by L and S cones. It can be seen below that the M information is removed, but the M component of the new pixel is not entirely empty. It contains a certain amount of information from the L and S cones; because that M light is seen by the eye but instead it is perceived as being from the L and S wavelength bands. This requires another matrix multiplication operation.

$$\begin{pmatrix} L_{deut} \\ M_{deut} \\ S_{deut} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0.49421 & 0 & 1.24827 \\ 0 & 0 & 1 \end{pmatrix} * \begin{pmatrix} L \\ M \\ S \end{pmatrix}$$

This leads to removal of the medium wavelength information and the new M pixel is filled appropriately, thus, deuteranopia has been simulated. To get a view for the results, we simply convert back to the RGB color space by once again performing matrix multiplication on each LMS pixel. This time the matrix is the inverse of that found in Equation 1.We know that a simulator converts an original image into images perceived by Protanopia, Duetranopia, and Tritanopia. This will help a color vision person to easily understand how the color blind sees the particular image. An algorithm to describe the simulation process in detail is given below:

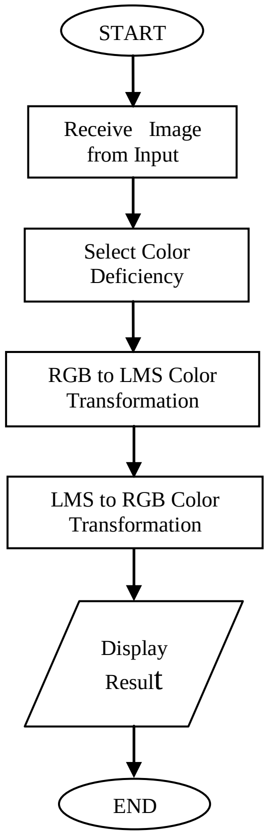

Fig 5.Algorithm for Simulation of Image

2) Delta E

Delta E is the second tool that proves helpful for assessing the impact of color blindness compensation techniques. Delta E is very beneficial for measuring color difference and determining the extent to which the given algorithm changes the original image, i.e. negatively affecting the image perceived by normal viewers. The Delta E is calculated for each pixel of an image. This algorithm considers two images in order to evaluate the color difference between them. Both images are first converted from RGB to the LAB color space. LAB pixel values represent lightness, L, and color coordinates A and B, based on a compressed version of the standard XYZ color oordinate space. The actual Delta E value for each pixel is calculated as follows:

$$\Delta E = \sqrt{(l_2 - l_1)^2 + (a_2 - a_1)^2 + (b_2 - b)^2}$$

The Delta E is calculated for each pixel of an image. This algorithm considers two images in order to evaluate the color difference between them. Both images are first

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converted from RGB to the LAB color space. LAB pixel values represent lightness, L, and color coordinates A and B, based on a compressed version of the standard XYZ color coordinate space. Usually it's an assessment of the color difference (delta) from a known standard. The total color difference computed with a color difference equation as mentioned below. In color tolerancing, the symbol DE is often used to express Delta Error. The difference between two color samples is often expressed as Delta E, also called DE, or ΔE. 'Δ ' is the Greek letter for 'D'. The resulting Delta E image will show how far apart visually the two samples are in the color 'sphere'. Standards Organizations specify Delta E tolerances. Different tolerances may be specified for grey and primary colors. A value of less than 2 is common for grey, and less than 5 for the primary CMYK and overprints. Delta E displays the difference as a single value for color and lightness. ΔE values of 4 and over will normally be visible to the average person, while those of 2 and over should be visible to an experienced observer. A recent study suggests that the Delta E value for a just noticeable difference is approximately 2.3. This will be worthy of consideration while assessing our results.

B. The Compensation Algorithms

In order to meet the requirements for guiding the design of visualizations for persons having CVD, many algorithms are designed to adjust images in such a way that color blind viewers are able to perceive the detail originally lost due to their color blindness. This has been studied in detail by [14][15][16]. Besides these, many more techniques are available but we choose to concentrate on following three as they provide some amount of theoretical diversity.

1) LMS Daltonization
2) RGB Color Constrasting
3) LAB Color Correction

1) LMS Daltonization

Daltonization is a procedure for adapting colors in an image or a sequence of images for improving the color perception by a color-deficient viewer. The process of LMS daltonization uses the information lost in the deuteranopia simulation so as to improve the original image [14]. Here, the lost information from the original simulation undergoes conversion from the LMS color space to RGB and then it is mapped to the wavelengths perceptible to the viewer, in this case long and short wavelengths (mostly red and blue). Now this information is shifted to colors that can be seen by the viewer and it is then added back to the image. For this the conversion from LMS to RGB color spaces is to be done. The lost information, now as RGB pixels, is mapped using the following matrix multiplication.

$$\begin{pmatrix} R_{map} \\ G_{map} \\ B_{map} \end{pmatrix} = \begin{pmatrix} 1 & 0.7 & 0 \\ 0 & 0 & 0 \\ 0 & 0.7 & 1 \end{pmatrix} * \begin{pmatrix} R_{lost} \\ G_{lost} \\ B_{lost} \end{pmatrix}$$

This operation does nothing to the lost red and blue information, but it definitely shifts the lost green partially into red and partially into blue. These new mapped RGB components are added to the original image. Finally, the image is checked and concatenated to ensure that no pixel value rises above one or below zero.

Following flowchart shows the algorithm steps undertaken while performing Daltonization.

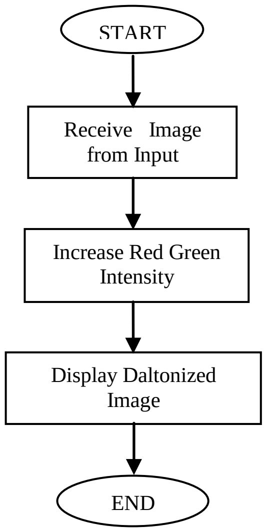

Fig 6.Algorithm of Daltonization

2) RGB Color Constrasting

Another technique that proves beneficial while considering the image modification is the colour contrast method. It adjusts the values of image's RGB so as to enhance the contrast between red and green. It finely results in making green pixels appear to be bluer. This is proved to be efficient in modification of an image in respect to enhancement of its contrast [15]. The process involves halving every pixel in the original image so as to provide room for pixel values to be increased.

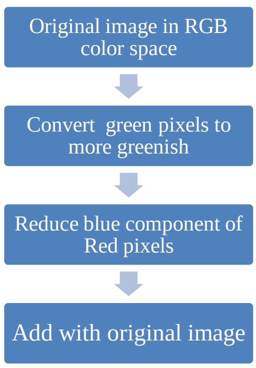

Fig 7 Image color enhancement process

For each pixel, three operations are undertaken. The first step: to increase the value of the pixel's red component relative to pure red. Reds further from pure red are increased significantly while reds already very close to pure red are only marginally increased. Second step: the green component of each pixel is manipulated next by applying exactly the same logic as that used on the red components. Finally, the value of the blue component is reduced for pixels that are mostly red. Moreover, for the

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pixels that are mostly green, the blue component is increased.

The scaling values here are determined through experimental evidences found through trial and error with color blind subjects.

3) LAB Color Correction

The motive of this algorithm is to modify reds and greens of an image to increase color contrast and clarity for a color blind individual [16]. It differs from RGB Color Contrasting in the respect that it is performed in the LAB color space. The algorithm generally operates as follows. The conversion of original image pixels from RGB to LAB color space is performed. The first operation involves each pixel's A component, where a positive A means closer to red and negative A means closer to green. Similar to RGB Color Contrasting, this A value is adjusted relative to its maximum, making positive values a bit more positive and negative values a bit more negative. Now, in each pixel the B component is adjusted relative to how green or red it is in order to bring out blue and yellow hues in the image. Finally, L, the brightness of the pixel, is also considered and adjusted relative to the pixels A value. Conversion of image back to the RGB color space is done and it is concatenated to ensure pixel values lie between zero and one. As compared to RGB Color Contrasting, there is lack of clear theoretical basis in this algorithm as it is also based upon experimental procedures that rely mostly on trial and error in the presence of a color blind viewer.

V. RESULT & ANALYSIS

For the purpose of implementation of the algorithms, we have considered an image of flowers.

Fig 8(a) Fig 8(b)

The result of implementation of these methods is expected as shown above. Here the original image and image seen by a deuteranopia patient are shown in Fig 8(a) and Fig 8(b) respectively. The original image consists of different colors which are orange red, green, yellow and blue. It is observed that a normal person can distinguish these different colors but a person affected by deuteranopia can't distinguish red and green. So first this original image is taken in RGB color space shown in Fig 8(a), then it is simulated so as to understand the perception of a deuteranopic viewer, it is shown in Fig 8(b).

Fig 8(c) Fig 8(d)

Image adjustment technique is applied, through the Daltonization process, on original image, which is shown in Fig 8(c) and Fig 8(d) shows how it is seen by the CVD person.

Fig 8(e) Fig 8(f)

Then the color contrast enhancement shown in Fig 8(e) has been done and perception of a deuteranopic viewer can understood by Fig 8(f).

Fig 8(g) Fig 8(h)

After enhancing, the contrasted image is used for LAB color correction for the deuteranopia patients. The LAB color corrected image is shown in fig 8(g) and in the next step, the LAB color corrected image as seen by CVD viewer is shown in fig 8(h).

A function Delta E is evaluated so as to know the difference between two images. In this case, we have considered the original image and the color contrasted image and we have evaluated Delta E in the image form as shown in fig 8(i). In this case, we have considered the original image and the color contrast image to obtain the Delta E image. This will provide us with the image difference between the two images taken into account. We

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can visualize the extent to which the original image has changed.

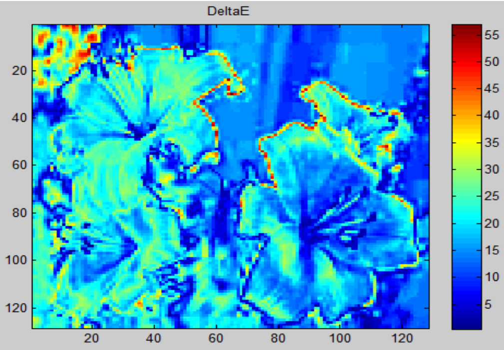

Fig 8(i)

One can compare the three algorithms on the basis of efficient and clear perception of the CVD viewer. RGB color contrasting proves to be yielding better results as compared to Daltonization and LAB color Correction.

Elapsed Time:
Another parameter which plays a vital role in deciding the efficiency of a system is the Elapsed Time. It is defined as the time taken by a system (algorithm) to produce the desired output in the form of image. It is measured in seconds. The less the elapsed time, the fast is the system. Here the elapsed time taken by all the three algorithms when applied on the images is shown in the tabular form below:

TABLE IIIII: ELAPSED TIME

Algorithm Image	LMS Daltoni-zation	RGB Color Contrasting	LAB Color Correction
Flowers	10.383265 s	0.838117 s	1.214104 s

VI. CONCLUSION

Approximately two hundred million individuals around the world are affected by CVD that significantly impacts their professional and personal lives. The proposed paper helps to understand this condition and provide solutions that improve the quality of life of these individuals, and their accessibility to technology. This paper proposes a novel Image Modification algorithm for people with CVD. Depending upon the application, the appropriate method can be selected amongst the various approaches that are available for adjustment and modification of images. The proposed paper is expected to show how the contrasting technique changes the image drastically for both color blind and non-color blind viewers; it also compares this technique with daltonization and color correction methods. With the help of these algorithms, the CVD viewer will be able to perceive the information that was lost due to his colour blindness. This paper gives us the opportunity to see the world through the eyes of someone suffering from colorblindness and explores the effectiveness of different attempts to improve their world. It is humbling to have this opportunity to learn from the perspective of others.

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